A DIRECT 3-D SHAPE MODELING SYSTEM

Ken-ichi Kameyama and Koichi Ohtomi

Research and Development Center
Toshiba Corporation
4-1,Ukishima-cho, Kawasaki-ku,Kawasaki,210 Japan
E-mail : kameyama@mel.uki.rdc.toshiba.co.jp

ABSTRACT

This paper describes a newly developed 3-D shape modeling system based on constructive solid geometry (CSG), in which a direct and interactive shape modeling process is supported. This feature is realized by a voxel model for real-time set operations, and a volume scanning display for the direct visualization of the voxel model, besides the CSG model for data structure management. The set operations on the voxel model can be executed as simple bit calculations, and therefore, the voxel data for the set object can be created in real time. The volume scanning display is a suitable device for presenting the voxel data, since the voxel can be directly corresponded to the bit image of the display, especially when the display has a cubic scanned volume. There is no need for intensive calculations to display the set objects, which is different from conventional CSG modelers, and therefore, a direct and interactive shape modeling environment can be realized. Furthermore, the volume scanning display can provide exact 3-D images without goggles or glasses, which is very useful for a direct modeling environment. Although the current system is still in an elementary level, the concept should be useful in an actual modeling environment.

1. INTRODUCTION

Current 3-D shape modelers are very powerful in creating and representing various shapes, but the 3-D shape modeling process itself is still difficult and time-consuming. The main reason is that conventional 3-D modelers can not support an interactive trial and error design process. A new system, especially a new interface which realizes real-time and direct shape manipulation, is necessary for improving design efficiency.

There have been several works related to direct 3-D modeling. In a system like [1],[2], or [3], the object shape is represented using B-spline surfaces and is interactively deformed by transferring the control points. In virtual sculpting [4], the object represented by voxel data is deformed by cutting away the voxels with a space sensor as a virtual tool.

Although these systems realize interactive processing in modeling, they do not seem to be acceptable in actual shape design, since these systems can support only limited types of shape creation or can not reproduce a shape which has been previously designed [4]. For example, models like [1], [2] and [3] can not support global deformation, such as making a hole or object subtraction.

Therefore, functions for both a real-time interactive Boolean set operation and shape data management mechanisms are indispensable for actual modeling systems. The problem for realizing these functions is that a set operation usually requires intensive calculations for detecting and displaying intersections. It is almost impossible to make a system interactive in a conventional shape modeling framework.

The system presented here employs a voxel model for real-time set operations, a volume scanning display for the graphical output of the voxel objects, and a CSG for shape data structure management. The set operations on the voxel model can be executed in real time, since the operations are executed as simple bit calculations. Each voxel in this case can directly correspond to a bit image in a 3-D frame memory for a volume scanning display, and therefore, the object set image can be directly presented as an exact 3-D image. Consequently, a user can interactively execute the set operations in the modeling process. Furthermore, the resulting shape is immediately stored in a CSG tree, and can be reproduced or reused afterwards.

In the following sections, the subject is focused on the volume scanning display and the methods for interactive shape modeling. Simple examples using this system are also described.

2. VOLUME SCANNING DISPLAY [5]

Figure 1 shows the principle of the volume scanning 3-D display. The panel is mounted with LEDs which are arranged lengthwise and breadthwise, and the section image of each 3-D object is displayed in accordance with the position of the panel. If the panel slides back and forth quickly, the section images along the moving direction are fused and a 3-D image can be perceived by the afterimage phenomenon. The image is created in a physical 3-D space, and therefore, the display has a wide field of view (Fig.1), which is useful for reviewing the object shape from different viewpoints. Table 1 shows the display specifications and Fig.2 is an exterior view of the display.

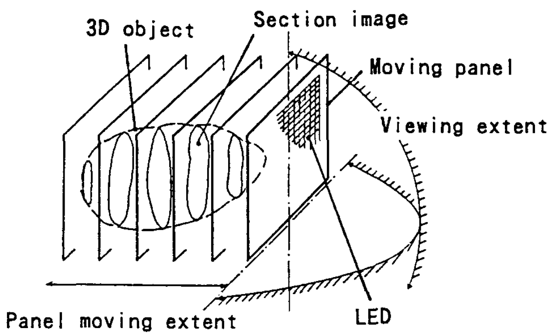

Fig. 1 Principle of volume scanning display

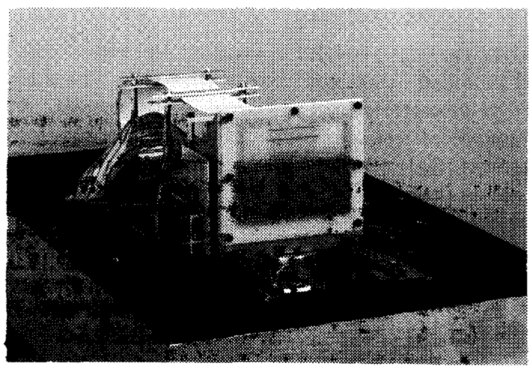

Fig. 2 Exterior view

Table 1

Display extent	94x30x50 [mm]
Picture elements	48x16x50 [dots]
Refreshing(Max)	30 [times/sec]
Color	Orange (610 [nm])
Brightness	50~100 [mcd/m^2]

This display can create a precise cubic scanned volume by mechanically converting a motor's rotation into a reciprocating motion (using a *Scotch-Yoke* mechanism). Therefore, a 3-D image of the voxel object can be directly presented on the display, since the voxel space on 3-D Cartesian coordinates easily corresponds to the display frame memory. In this system, only one bit is assigned to a voxel, since the voxel for representing the object shape requires only two values: exist (1) and non-exist(0).

There are the following two problems in presenting modeling shapes on this display.

(1) Conventional graphic methods like shading or hidden surface elimination are of no use for displaying a solid object, since the images are basically translucent.

(2) A user can not reach or touch the object image, since it is displayed in the scanned volume.

For problem (1), the system has three basic drawing methods, namely wire, surface, and solid (Fig.3). A user can distinguish both the outer and the inner edge of the solid object in case of wire or surface drawings. Therefore, the system mainly uses wire or surface drawings for the graphical outputs. Solid drawings are used only for obtaining the wire or surface drawings for the set objects.

For the 2nd problem, the system employs a virtual pointer (Fig.4) as the 3-D input device, in which the manipulation point in the image space is calculated by the position and the orientation of the control point in the user's hand (Fig.5).

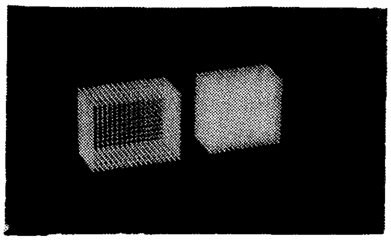

Fig. 3 Drawing methods
(surface drawing and solid drawing)

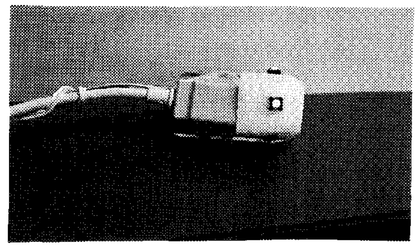

Fig. 4 Virtual pointer

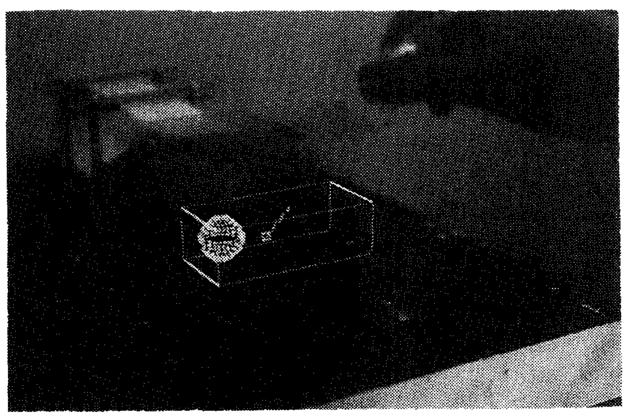

Fig. 5 Manipulation using virtual pointer

3. INTERACTIVE SHAPE MODELING

The system employs a CSG manner modeling environment, since CSG is the most concise method among the major approaches to solid modeling [6]. The object in CSG is constructed by Boolean combinations (*union* : $\cup$, *intersection* : $\cap$, and *set difference* : $\setminus$) of primitive objects such as boxes, cylinders, spheres, and so on. The result is represented as a CSG tree (Fig.6).

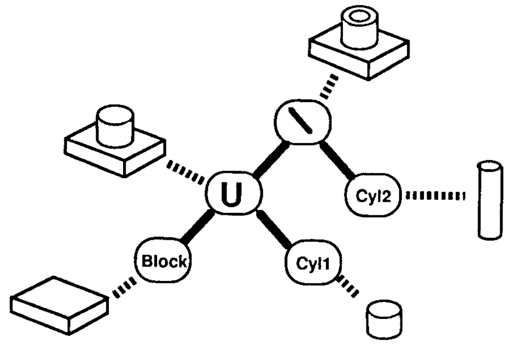

Fig. 6 CSG tree (example)

One modeling cycle of this system is as follows.

1) A user creates or loads three images (wire, surface, and solid) of a base object **A**. The system automatically presents the surface image in a certain position of the display, and he/she determines its initial location.
2) He/she does the same things on a combining object **B**.
3) He/she selects the type of set operation, and moves **B**. The graphical outputs for **A** and **B** are automatically changed by the type of set operations (Fig.7), and the intersection part is displayed like Fig.7. Consequently, a user can interactively check or evaluate the combined shape. In the combination process, the drawings are obtained by the following algorithms (w(A), h(A), and s(A) designate wire, surface, and solid drawings, respectively).
   a) Union
      $h(A) \cup h(B)$
   b) Intersection
      $(h(A) \cap s(B)) \cup (s(A) \cap h(B)) \cup w(A) \cup w(B)$
   c) Set difference
      $(h(A) \setminus s(B)) \cup (s(A) \cap h(B)) \cup w(B)$

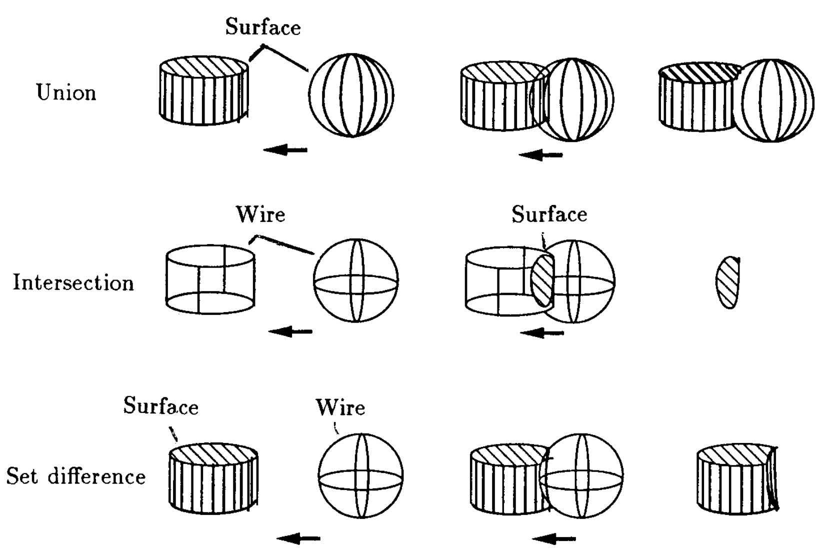

Fig. 7 Display in combining process

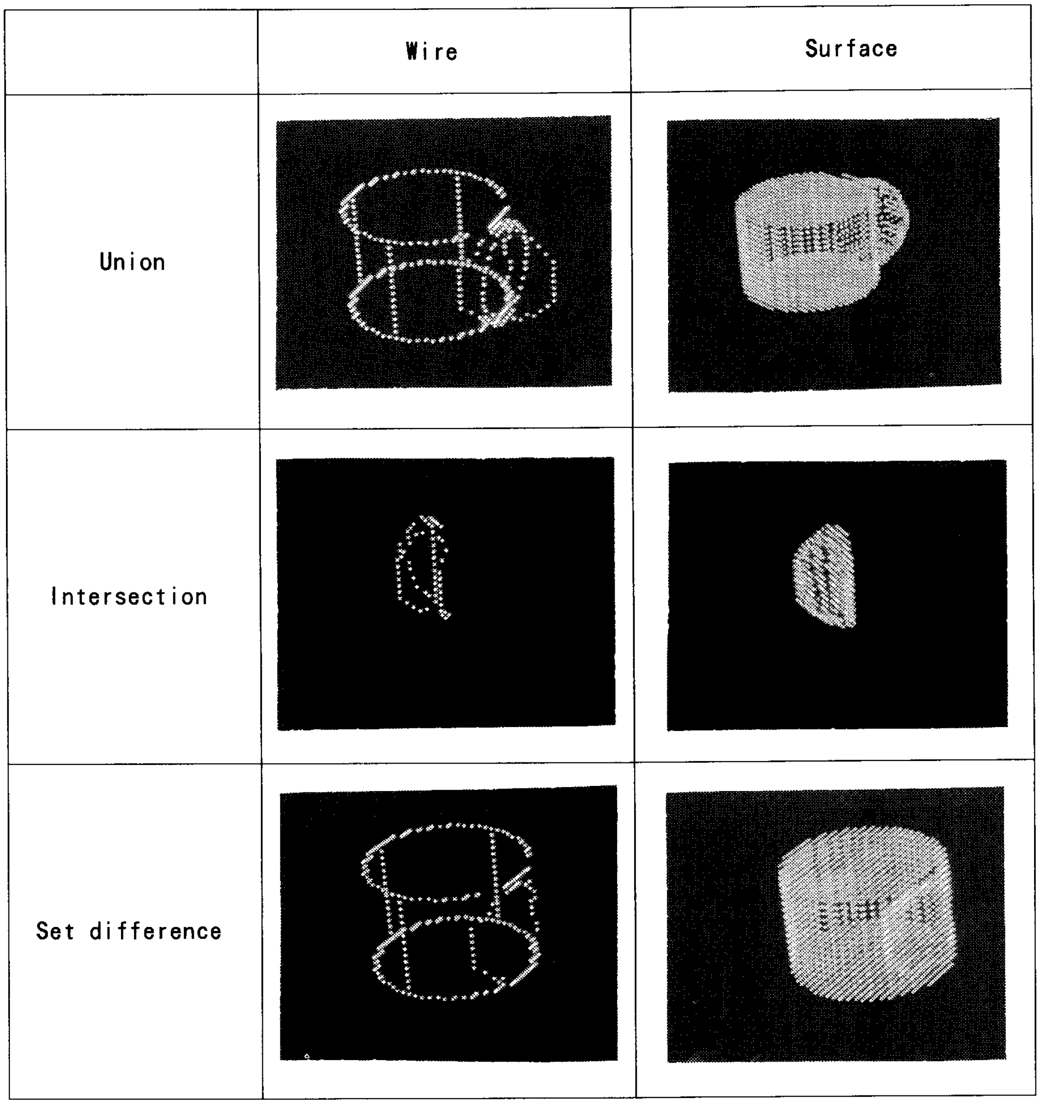

Fig. 8 Combined images on volume scanning display (cf. Fig. 7)

4) If he/she determines the location of **B**, the system automatically updates the CSG tree and calculates the wire, surface, and solid images of the combined object. The image data are temporarily stored at the nodes in the CSG tree, and used in the next cycle. The algorithms for obtaining the wire, surface, and solid image for the combined object are as follows.

   i) Intersection
      Wire: $(s(A) \cap s(B)) \cup (s(A) \cap w(B)) \cup (h(A) \cap h(B))$
      Surface: $(h(A) \cap s(B)) \cup (s(A) \cap h(B))$
      Solid: $s(A) \cap s(B)$

   ii) Union
      Wire: $(w(A) \setminus s(B)) \cup (w(B) \setminus s(A)) \cup (h(A) \cap h(B))$
      Surface: $(h(A) \setminus s(B)) \cup (h(B) \setminus s(A))$
      Solid: $s(A) \cup s(B)$

   iii) Set difference
      Wire: $(w(A) \setminus s(B)) \cup (s(A) \cap w(B)) \cup (h(A) \cap h(B))$
      Surface: $(h(A) \setminus s(B)) \cup (s(A) \cap h(B))$
      Solid: $s(A) \setminus s(B)$

   Actual images of the volume scanning display are shown in Fig.8.

The algorithms presented here are only for providing graphical images, but are useful for interactive object modeling and CSG tree creation. Accurate numerical properties and formulas for the generated surfaces or lines should be calculated after the whole CSG tree is created, since these calculations are usually too intensive for the interactive system itself.

5. SUMMARY AND CONCLUSION

A newly developed 3-D shape modeling system in which a user can directly and interactively create a 3-D object has been described. This feature is realized by a voxel model for real-time set operations, and a volume scanning display for the direct visualization of the voxel model, besides the CSG model for data structure management.

When a user wants to combine two objects in the modeling process, the system executes a Boolean set operation on the object image in real time, and interactively presents the graphical image of the combined object. After he/she checks and confirms the object shape, the system updates the CSG tree.

Although the ability of the current system is limited, the concept should be useful in an actual design environment. The following researches will be required.

(1) Development of effective algorithms for sweeping primitives or rotational transformation.
(2) System performance evaluation.

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